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Estimation of Emissions from Charcoal Lighter Fluid and Review of Alternatives

Radian Corp., Research Triangle Park, NC

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ESTIMATION OF EMISSIONS FROM CHARCOAL LIGHTER FLUID AND REVIEW OF ALTERNATIVES

FINAL REPORT

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16. ABSTRACT The report gives results of an evaluation of emissions of volatile organic compounds (VOCs) from charcoal lighter fluid, a consumer product consisting entirely of volatile constituents. An estimated 46,250 tons (42,000 Mg) of charcoal lighter fluid is used in the U.S. each year. VOCs contribute to the formation of ozone; therefore, the ozone nonattainment issue has focused attention on VOCs emitted from many sources. VOCs are emitted when charcoal lighter fluid is used, but these emissions are difficult to quantify. Evaporative VOC losses occur from the lighter fluid prior to ignition, and combustion VOC losses occur from burning lighter-fluid-soaked charcoal briquettes. This study evaluates tests conducted to date on charcoal lighter fluid emissions. The information is most complete for evaporative VOC losses. The estimates vary greatly, however, based on the length of time between application of the lighter fluid and ignition. Estimates of evaporative VOC losses range from 244 to 6,937 tons/yr (220 to 6,300 Mg/yr). The best estimate of VOC evaporative emissions is 1,110 tons VOC/yr (1,000 Mg/yr). Approximately 14,500 tons VOC/yr (13,150 MG/yr) is expected to be emitted from the combined evaporation and combustion of charcoal lighter fluid. The limited tests conducted to date have not distinguished lighter fluid from charcoal briquette combustion emissions.

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a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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ABSTRACT

Volatile organic compounds (VOC) are known to contribute to the formation of ozone; therefore, the ozone nonattainment issue has focused attention on the VOC emitted from many stationary, mobile, and area sources. One group of area sources which have received recent attention by the U. S. Environmental Protection Agency and a number of State and local air pollution control agencies is the use of a wide variety of VOC containing consumer products. The focus of this study is to evaluate emissions of VOC from charcoal lighter fluid, one consumer product comprised entirely of volatile constituents.

Volatile organic compounds are emitted when charcoal lighter fluid is used, but these emissions are difficult to quantify. Evaporative VOC losses occur from the lighter fluid prior to ignition, and combustion VOC losses occur from burning lighter fluid-soaked charcoal briquettes.

The information from studies conducted to date is most complete for the evaporative VOC losses. The estimates vary greatly, however, based on the length of time between application of the lighter fluid and ignition of the fire. The best estimate of VOC evaporative emissions is 1,110 tons VOC/yr (1,000 Mg/yr), and is derived from one of the tests evaluated in this study. This estimate lies in the mid range of the estimates reviewed, and is based on the assumption that a 5 minute soaking period is most representative of actual usage practices.

Approximately 14,500 tons VOC/yr (13,150 Mg/yr) are expected to be emitted from the combined evaporation and combustion of charcoal lighter fluid. The limited tests conducted to date have not distinguished the lighter fluid combustion emissions from the charcoal briquette combustion emissions.

In this study, current usage patterns, emission estimates, ease of use, and costs to consumers are evaluated for the alternatives to charcoal lighter fluid. In general, electric grills produce the lowest emissions, followed by liquified petroleum gas and natural gas grills. Chimney and electric starters produce charcoal combustion emissions only, and solid and gel starters should produce fewer emissions than self-starting charcoal or charcoal lighter fluid. Emissions from self-starting charcoal result from the combustion of the volatile component and the charcoal itself.

NOTICE

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SECTION 1
INTRODUCTION

In 1988, 101 cities in the United States were unable to meet the Federal government's air pollution standard for ozone. Volatile organic compounds (VOC) are known to contribute to the formation of ozone; therefore, the ozone nonattainment issue has focused recent attention on the VOC emitted from many area sources, including consumer products. Substantial emission controls have already been placed on many stationary and mobile sources of VOC, and many area sources could be controlled to further reduce VOC emissions in populated areas.

One consumer product category of interest regarding the possible emission of VOC is charcoal lighter fluid. This product category is being evaluated by the U. S. Environmental Protection Agency (EPA) because it is comprised entirely of volatile constituents. Petroleum naphtha and petroleum distillate are the only ingredients, though some manufacturers may add a small amount of perfume. The VOC emissions are less than 100 percent of the lighter fluid applied, however, because some of the lighter fluid is combusted to form carbon dioxide and water vapor.

The South Coast Air Quality Management District (SCAQMD) in California was the first regulatory agency in 1989 to investigate charcoal lighter fluid as a source of atmospheric VOC. Possible control measures considered by the SCAQMD for this product category are:

- Prohibit the sale of grills that require lighter fluid;
- Require that lighter fluid be reformulated to contain fewer photochemically reactive constituents; and
- Restrict the use of lighter fluid during summer smog episodes and discourage its use in general through public information programs.

The purpose of this study is to evaluate the limited studies available and estimate the magnitude of emissions from charcoal lighter fluid. Section 2 presents the results and conclusions concerning charcoal lighter fluid VOC emissions, and evaluates the significance of these emissions relative to VOC

emissions from other consumer products. The derivation of the lighter fluid emission estimates is described in Section 3, along with a discussion of the limitations of each estimate. Section 4 presents an evaluation of the various alternatives to charcoal lighter fluid, and examines the current use patterns, potential emissions, ease of use, and cost to consumers for each alternative. The references cited in this study are provided in Section 5.

SECTION 2
RESULTS AND CONCLUSIONS

LIGHTER FLUID EMISSION ESTIMATES

Volatile organic compounds are emitted when charcoal lighter fluid is used, but these emissions are difficult to quantify. Evaporative VOC losses occur from the lighter fluid, and combustion VOC losses occur from burning lighter fluid-soaked charcoal briquettes. Limited tests have been performed to date, and none have attempted to distinguish the lighter fluid combustion emissions from the charcoal briquette combustion emissions.

Three studies that attempted to estimate VOC emissions from charcoal lighter fluid use were reviewed in this study. The results of these studies are summarized here, and are discussed in more detail in Section 3. Table 1 presents a summary of the emissions information as found in studies by the South Coast Air Quality Management District;[1,2] U. S. Testing, an independent testing firm hired by the Clorox Company;[3] and the U. S. Environmental Protection Agency, Air and Energy Engineering Research Laboratory (AEERL). The SCAQMD estimate is not based on actual testing, but is based instead on assumptions of the emission factor and evaporation rate for charcoal lighter fluid. The Clorox Company's test examines only evaporation of lighter fluid prior to ignition. The test conducted by the EPA is the most complete of those conducted to date in that evaporation and combustion emissions are monitored (Appendix B). However, it is difficult to distinguish the charcoal combustion emissions from those of the lighter fluid.

National emissions of VOC from lighter fluid use can best be estimated by combining the data provided by the Clorox Company and the EPA. The national estimate of 1,110 tons VOC/yr (1,000 Mg/yr) due to evaporation of charcoal lighter fluid lies in the mid range of the estimates reviewed, and is calculated from the evaporative data provided by the Clorox Company.

Evaporation and combustion of lighter fluid are estimated to yield a national total of 14,500 tons VOC/yr (13,150 Mg/yr), based on the EPA's test.

The SCAQMD recently conducted a more detailed evaluation of pollutant emissions from various methods of igniting charcoal briquettes.[4] The charcoal

TABLE 1. SUMMARY OF CHARCOAL LIGHTER FLUID EMISSION ESTIMATES

Source	Annual National Emission Estimate[a]	
	Evaporation (tons VOC/yr)	Evaporation and Combustion (tons VOC/yr)
South Coast Air Quality Management District	6,937 (6,300 Mg)	[b]
U. S. Testing (Clorox Company)	244 (220 Mg)	[b]
U. S. Environmental Protection Agency	2,780 (2,520 Mg)	17,200 (15,600 Mg)
Best Estimate[c]	1,110 (1,000 Mg)	14,500 (13,150 Mg)

[a]Based on an estimate of 46,250 tons/yr (42,000 Mg/yr) of charcoal lighter fluid used.[5]

[b]Not estimated.

[c]Derived from U. S. Testing and U. S. Environmental Protection Agency data.

ignition methods tested are discussed more fully in Section 4, and included an electric starter, charcoal lighter fluid, self-lighting charcoal, solid starter, and a chimney starter. The information contained in the SCAQMD report summary is included in Section 4 as a qualitative ranking of VOC emissions from the charcoal lighter fluid alternatives.

SIGNIFICANCE

It is useful to compare the estimates of total VOC emissions from charcoal lighter fluid to emissions from other consumer product categories. To put the lighter fluid VOC emission estimate into perspective, the VOC emissions from automotive products such as polishes and waxes, antifreeze, carburetor and choke cleaners, brake cleaners, engine degreasers, and engine starting fluid are compared. This comparison is valid because products in both categories typically are used only outdoors.

The estimate of 14,500 tons VOC/yr (13,150 Mg/yr) emitted from the use of charcoal lighter fluid most closely compares to that from the use of carburetor and choke cleaners of 13,093 tons VOC/yr (11,880 Mg/yr).[6] California ranks carburetor and choke cleaners as 14th of 47 consumer product subcategories that produce photochemically reactive organic compounds (PROC). This subcategory is estimated to produce 1.5% of the total PROC emissions from consumer product usage in California.[6]

EVALUATION OF ALTERNATIVES

The alternatives to charcoal lighter fluid evaluated in this study are:

- Electric, liquified petroleum gas (LPG), and natural gas grills which replace the need for lighter fluid and charcoal;
- Chimney and electric starters which replace charcoal lighter fluid and are used in conventional grills;
- Solid and gel starters for use in conventional charcoal grills; and

- Self-starting charcoal, which can be purchased in a combustible bag or loose, and is used in conventional grills.

These alternatives are discussed in more detail in Section 4. Current usage patterns, emission estimates, ease of use, and costs to consumers are evaluated. In general, electric grills result in the lowest emissions, followed by LPG and natural gas grills. Chimney and electric starters produce charcoal combustion emissions only, and solid and gel starters should produce fewer emissions than self-starting charcoal or charcoal lighter fluid.[4] Emissions from self-starting charcoal result from the combustion of the volatile component in the briquettes or the bag and combustion of the charcoal itself.

CONCLUSION AND RECOMMENDATIONS

The potential emissions from the use of charcoal lighter fluid are significant enough to warrant further research in this area. On the basis of the information evaluated in this study, more testing should be conducted before a quantitative ranking of the VOC emissions from alternative outdoor cooking practices is made. An investigation of the emissions expected from the use of charcoal lighter fluid should first evaluate the length of time consumers allow the fluid to soak before ignition. Since virtually 100% of charcoal lighter fluid is volatile, the length of the evaporation period will have a large effect on total VOC emissions.

This point is best illustrated by the data provided by U. S. Testing.[3] If the lighter fluid is left on the charcoal for only 1 minute before ignition, then only 0.65% of the fluid applied evaporates. If the fluid is left on the coals for 10 minutes, then 4.9% of the fluid evaporates. The Barbecue Industry Association's[5] estimate that 46,250 tons (42,000 Mg) of lighter fluid were used in 1988 in the United States indicates that the emissions from evaporation of lighter fluid alone could range from 300 tons (270 Mg) VOC/year to 2,266 tons/year (2,050 Mg/yr).

It would be useful to conduct additional testing to distinguish lighter fluid combustion emissions from charcoal combustion emissions. Volatile organic compound emissions that result from charcoal combustion could be tested by igniting the charcoal with an electric starter.

Another factor that will greatly affect the estimate of VOC emitted from the use of charcoal lighter fluid is related to the EPA test that measures emissions as total hydrocarbons (THC). This test may have resulted in an overestimation of VOC released, since the measured THC emissions may include some organics that are not considered volatile under EPA's definition of VOC. By its regulatory definition, a volatile organic compound is any organic compound that participates in atmospheric photochemical reactions. The definition of VOC includes all organic compounds except: methane, ethane, methyl chloroform, methylene chloride, and seven chloroflurocarbons. These compounds are exempt because they have negligible photochemical reactivity. A measurement of THC thus would include methane and ethane concentrations that are not considered VOC.

In this test it was also difficult to separate the combustion emissions of the lighter fluid from the combustion emissions of the charcoal itself.

More investigation of the emissions from the alternatives (especially natural gas and LPG grills) discussed in this report also is needed. Both propane and methane are considered to burn cleanly, but emissions from these grills should be quantified before recommending them to consumers as appropriate substitutes for charcoal grills.

SECTION 3
LIGHTER FLUID EMISSION ESTIMATES

SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT ESTIMATE[1,2]

The South Coast Air Quality Management District in California was the first regulatory agency in 1989 to estimate VOC emissions from charcoal lighter fluid usage. The SCAQMD estimated the District's reactive organic emissions to be 2 tons/day (1.8 Mg/day) from the use of charcoal lighter fluid. This estimate was based on lighter fluid sales figures, an emission factor for lighter fluid between 0.1 and 0.5, and the assumption that 10 to 25% of the charcoal lighter fluid applied evaporates prior to ignition. The density of lighter fluid was assumed to be equal to that of kerosene (6.91 lbs/gal or 0.828 g/ml). The amount of lighter fluid used per year in the District was based on an annual sales figure for the United States, scaled down by population density. The average cost for lighter fluid was assumed to be $1.50/qt.[2]

The SCAQMD, however, used national sales data for lighter fluid which are believed to be overestimated. The amount of lighter fluid used nationally was later made available by the Barbecue Industry Association (BIA).[5] Their figure of 46,250 tons (42,000 Mg) used in 1988 is approximately 55% of SCAQMD's figure.

An emission estimate can be made, however, based on SCAQMD's assumption of an average evaporation rate of 15% and the BIA's annual use figure of 46,250 tons/yr (42,000 Mg/yr). Using this information, nationwide VOC emissions from evaporation of lighter fluid are estimated to be approximately 6,937 tons/yr (6,300 Mg/yr).

THE CLOROX COMPANY'S INDEPENDENT TESTING FIRM ESTIMATE[3]

The Clorox Company hired an independent testing firm (U. S. Testing) to evaluate emissions of VOC due to evaporation of lighter fluid applied to charcoal. U. S. Testing applied 3.5 fluid ounces (103 ml) of lighter fluid to 2 pounds (0.9 kg) of charcoal and simulated outdoor cooking conditions (80°F and 50% relative humidity). The firm then weighed the pile of charcoal every 30 seconds, and established a linear relationship between time and

cumulative evaporation of lighter fluid. Figure 1 shows a plot of this relationship.

U. S. Testing then calculated a linear regression curve based on the data shown in Figure 1 and in Appendix A, to yield the equation:

Percent Evaporated = 0.478 x (saturation time in minutes) + 0.05

U. S. Testing estimated evaporation emissions from charcoal lighter fluid based on the sales information from the Barbecue Industry Association, and estimated total national VOC emissions due to evaporation alone to be 244.2 tons/year (220 Mg/yr). This estimate assumes that consumers follow the label instructions and allow the lighter fluid to soak for one minute before ignition.

U. S. Testing also estimated VOC evaporative emissions for the SCAQMD to be 6.93 tons/year (6.3 Mg/yr), or 0.038 tons/grilling day (0.03 Mg/grilling day).

This study is limited in that no attempt was made to estimate VOC emissions during combustion. In addition, this test may have assumed an unrealistically short soaking period (1 minute) of the lighter fluid. Another limitation of this test lies in the calculation of a linear regression. Since the regression is based on a time series of data from one test, the validity of the confidence interval is in question. In order to estimate a confidence interval, independent evaporative measurements from several tests with lighter fluid soaked-briquettes should be taken.

U. S. ENVIRONMENTAL PROTECTION AGENCY ESTIMATE

The AEERL in Research Triangle Park, NC conducted a test to monitor total hydrocarbon, carbon dioxide (CO_2) and carbon monoxide (CO) emitted from the evaporation and combustion of 100 ml (3.4 fluid ounces) of lighter fluid and 2 pounds (0.9 kg) of charcoal (Appendix B). Ambient conditions were simulated in the outbuilding where the test was conducted. The coals were allowed to soak for 15 minutes before ignition. Concentrations of THC, CO_2, and CO were measured every 5 minutes. Figure 2 presents the results of AEERL's measurements.

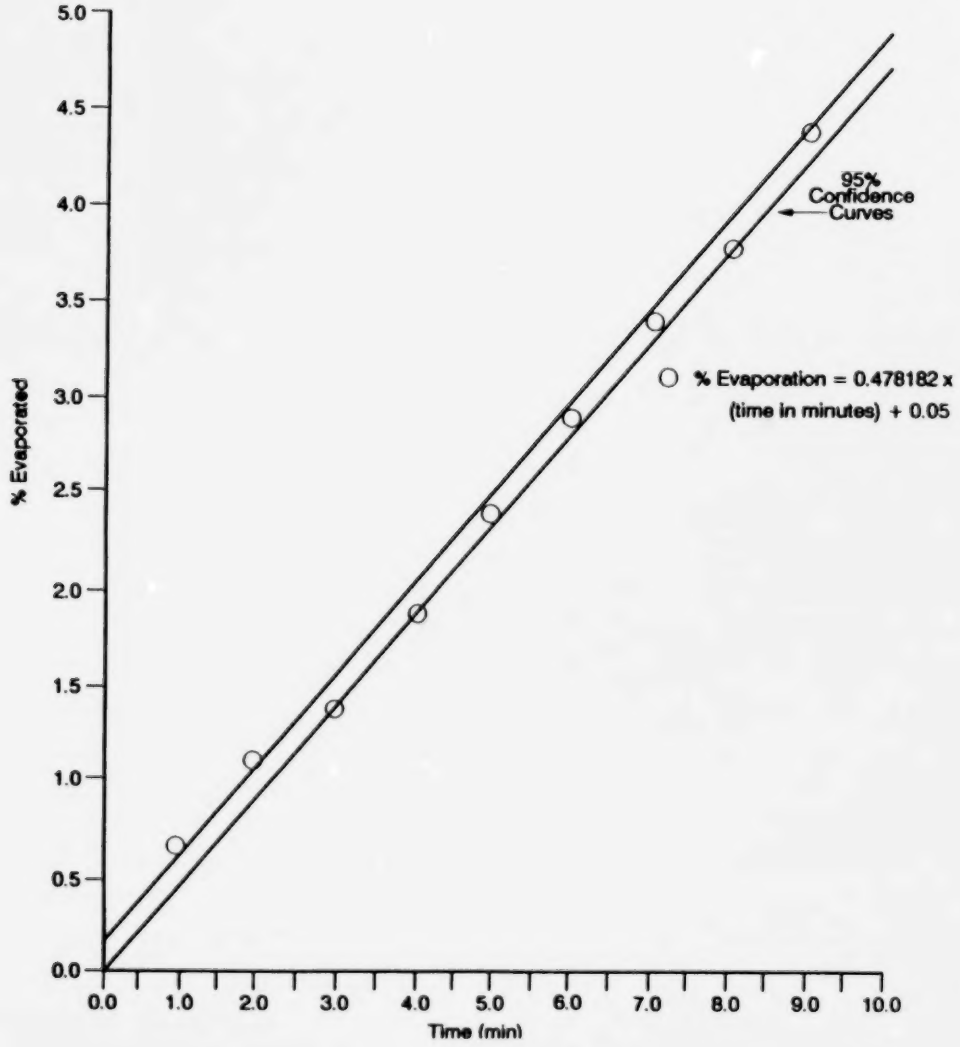

Figure 1. Evaporation of Lighter Fluid vs. Time [3]

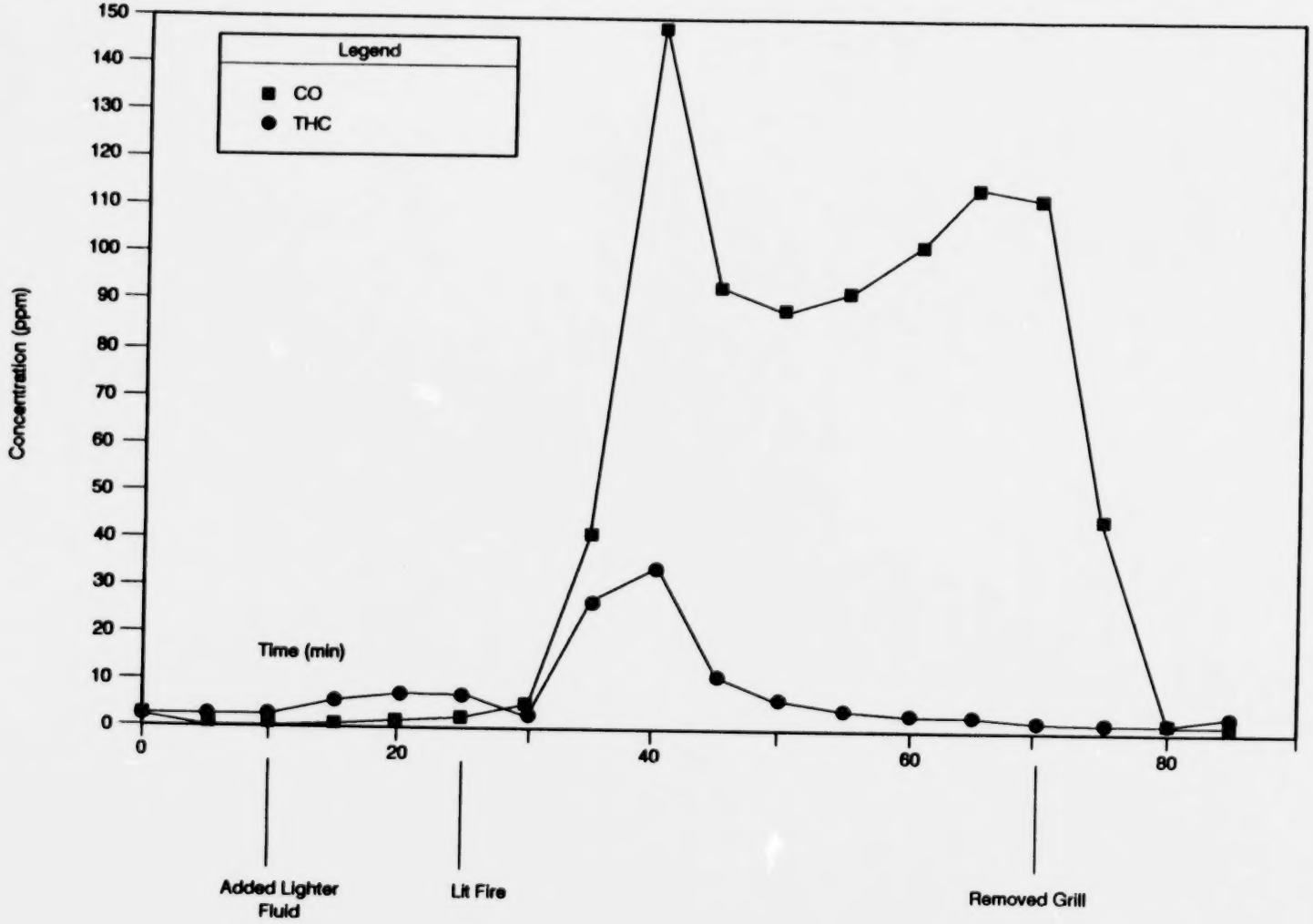

Figure 2. AEERL Charcoal Grill Emissions

Assuming an ambient THC concentration of 2 ppm, as measured prior to application of the lighter fluid to the charcoal and after the grill was removed, the concentration measurements for CO_2, CO, and THC were converted to emission rates (lbs/min). The calculations for this conversion are included in Appendix C. Based on the calculated emission rates, it was determined that prior to combustion, 6% of the lighter fluid had evaporated. Using the BIA's estimate of 46,250 tons (42,000 Mg) of lighter fluid used per year, this yields a total of 2,780 tons (2,520 Mg) of VOC per year from a 15 minute evaporation period.

To provide an estimate of the emissions from evaporation and combustion of lighter fluid, it was assumed that all emissions of THC are from lighter fluid for the first 25 minutes of combustion. This is a conservatively high estimate since the lighter fluid should burn off well before this time and the charcoal should produce some of the measured THC emissions. This estimate is 17,200 tons/year (15,600 Mg/yr) of VOC emitted from both evaporation and combustion, or 37.1% of the charcoal lighter fluid used.

Three potential sources of overestimation in this analysis are:

- The measured THC emissions may include some organic compounds that are not considered volatile under EPA's definition of VOC (i.e., methane, ethane);

- The measured THC emissions from combustion that are attributed to the lighter fluid may actually be affected by emissions from the combustion of the charcoal; and

- AEERL's 15 minute saturation period may not represent actual consumer usage practices, and may be an overestimation of the length of time users allow the lighter fluid to soak into the briquettes prior to lighting the fire.

ESTIMATE DERIVED FROM U. S. TESTING AND U. S. ENVIRONMENTAL PROTECTION AGENCY

On the basis of the information presented above, an estimate of VOC emissions from evaporation and from evaporation and combustion of lighter fluid can be derived by using a combination of U. S. Testing's data and the

test data from AEERL. The biggest discrepancy in the evaporation estimate from these two tests lies in the length of the soaking period. U. S. Testing let the lighter fluid soak for 1 minute and estimated evaporative losses of 0.528%, while AEERL's 15 minute saturation period produced 6% evaporative losses.

A best estimate was made based on the assumption that a 5 minute soaking period is most representative of actual usage practices. Using the evaporative data provided by U. S. Testing (Figure 1 and Appendix A) and an assumed soaking period of 5 minutes yields an emission estimate (for evaporation only) of 2.4 percent.

The BIA's estimate of 46,250 tons (42,000 Mg) of lighter fluid used per year indicates that 1,110 tons (1,000 Mg) of VOC may be emitted from the evaporation of lighter fluid prior to combustion.

A better estimate of VOC emissions from both evaporation and combustion may be less conservative than the the EPA's calculated 17,200 tons/year (15,600 Mg/yr) by assuming the THC emissions are from the lighter fluid until THC and CO emissions begin to decrease at t = 40 minutes rather than t = 50 minutes (Figure 2). This estimate is based on the assumption that no lighter fluid is present after t = 40 minutes, and the remaining THC emissions are from combustion of the charcoal briquettes only. The estimate yields total VOC emissions from evaporation and combustion of 14,500 tons/year (13,150 Mg/yr), or 31.3% of the lighter fluid used.

SECTION 4
EVALUATION OF ALTERNATIVES TO CHARCOAL LIGHTER FLUID

The current use patterns, potential emissions, ease of use, and costs to consumers for the alternatives to charcoal lighter fluid are reviewed in this section.

The available alternatives include:

- Grills that eliminate the need for both charcoal and lighter fluid, such as electric, liquified petroleum gas, and natural gas grills;

- Chimney and electric starters, that replace lighter fluid and are used in conventional grills;

- Solid and gel starters as substitutes for charcoal lighter fluid for use in conventional grills; and

- Self-starting charcoal, in a combustible bag or loose, used in conventional grills.

Tables 2 through 7 compare the current use patterns, emissions, ease of use, and costs for each of these alternatives. The most popular outdoor cooking method currently uses charcoal and lighter fluid (Tables 2 and 3).[5] As shown on Table 4, this method is expected to produce the highest emissions, however.[4] These emissions are from the evaporation of lighter fluid and the combustion of lighter fluid and charcoal.

Electric grills produce negligible emissions, have a low initial purchase cost, and the cost of electricity used per fire is negligible. Increased emissions associated with generating additional electricity from the utility plants were not considered because the increased use of electricity is considered negligible (the rating for an electric grill is similar to that for a toaster oven). As with the other alternatives that eliminate the need for charcoal, there is no need for ash cleanup, and better control of cooking temperatures can be achieved. This method's only disadvantage is its lack of portability (an electric outlet must be accessible).

TABLE 2. CURRENT USE PATTERNS FOR GRILLS[7]

Type of Grill	Percent of U.S. Households Using:
Charcoal grills	76%
Gas grills (natural or LPG not specified)	23.3%
Electric grills	4%

TABLE 3. CURRENT CHARCOAL IGNITION METHODS[5]

Charcoal Ignition Method	Tons of Charcoal Ignited
Charcoal lighter fluid	534,290 (68.3%)
Instant lighting	121,251 (15.5%)
Electric starter	66,493 (8.5%)
Chimney starter	20,339 (2.6%)
Solids	7,040 (0.9%)
(Unaccounted for)	32,855 (4.2%)
TOTAL	782,268

TABLE 4. EMISSION RANKING FOR CHARCOAL LIGHTER FLUID ALTERNATIVES[8,9,10,11,12]

Alternative	Comments
Electric grill	No emissions
Bottled gas (LPG) grill	Some emissions (water vapor, CO_2, and CO)
Natural gas grill	Possible formaldehyde emissions
Electric starter	Emissions from charcoal combustion
Chimney starter	Emissions from charcoal combustion
Solid starter	Emissions from charcoal combustion
Gel starter	Emissions from charcoal and alcohol-based gel
Self-starting charcoal (w/naphtha or mineral spirits)	Emissions from charcoal and naphtha or mineral spirits during combustion
Self-starting charcoal (w/naphtha) in a bag	Emissions from charcoal and naphtha during combustion, and particles from combustion of the bag
Charcoal with lighter fluid	Evaporation of lighter fluid and combustion of charcoal and lighter fluid

TABLE 5. EASE OF USE COMPARISON FOR ALTERNATIVE OUTDOOR COOKING PRACTICES[8]

Alternative	Comments
Electric and natural gas grills	Do not need lighter fluid or charcoal, no ash cleanup, good control of flame/heat; not portable, grill must have natural gas or electrical hookup
Bottled gas (LPG) grill	Do not need lighter fluid or charcoal, no ash cleanup, good control of flame/heat; must refill LPG, only table-top model is portable
Self-starting charcoal in bag	Do not need lighter fluid, one fire per bag
Self-starting charcoal not in bag	Do not need lighter fluid
Charcoal with lighter fluid	Base case for comparison
Chimney starter	Must remove chimney after coals heat
Electric starter	Must remove starter after coals heat, chance of destroying starter
Solid starter	Must carefully arrange coals, takes longer to start
Gel Starter	Difficult to achieve complete burn

TABLE 6. COST ESTIMATES FOR INITIAL PURCHASE OF GRILLS[8,13]

Alternative	Average Cost	Range
Natural Gas Grill:	$440.00	$340.00 - 540.00
Free Standing LPG Grill:	299.00	99.00 - 741.00
Tabletop LPG Grill:	31.00	25.00 - 49.00
Tabletop Electric Grill:	63.00	49.00 - 79.00
Free Standing Charcoal Grill:	61.00	19.00 - 138.00
Chimney Starter:	12.50	10.00 - 15.00
Electric Starter:	9.00	5.00 - 14.00

TABLE 7. COST PER FIRE FOR OUTDOOR COOKING ALTERNATIVES[8]

Product:	Cost per Fire
Self-Starting Charcoal in Bag	$1.29
Self-Starting Charcoal	0.87
Charcoal Briquettes with Solid Starter	0.45+0.30 =0.75
Charcoal Briquettes with Lighter Fluid	0.45+0.12 =0.57
Charcoal Briquettes with Gel Starter	0.45+0.11 =0.56
LPG	0.33
Electric Starter	negligible
Natural Gas	negligible
Electric Grill	negligible

Natural gas, predominantly methane, can only be used in grills that can be connected to a gas line. As shown in Tables 4 and 5, natural gas grills are the easiest to use. Some studies indicate that burning natural gas may produce formaldehyde emissions; however, no quantitative emissions data were located.[12] Other emissions are water vapor and carbon dioxide.[9] Natural gas grills are the most expensive alternative examined in terms of initial cost, but their estimated lifetime is 10 to 15 years (with $40.00 burner replacement every 5 years). The costs of this method and the LPG grills can also be considered in terms of eliminating the need for charcoal and charcoal lighter fluid. The cost of natural gas per fire is negligible.

The free standing LPG grill is not as easy to use as the natural gas grill because the propane fuel tanks must be refilled. The Consumer Union[8] estimates that it costs $9.00 to refill a 20-gallon tank, which will last for approximately 27 fires. The burners for these grills are generally guaranteed for 5 years, and average replacement cost is $30.00. The portable tabletop LPG grill is much less expensive than the free standing model, but is expected to have a shorter lifespan (with burner replacement needed after 2 years).

The potential emissions from this alternative are expected to be negligible. Carbon dioxide and water vapor may be emitted,[9] as well as carbon monoxide. The American Gas Association, however, requires emissions from combustion of LPG to be less than 0.08 percent carbon monoxide in an air-free sample of flue gas.[9]

The other alternatives discussed here require the use of some type of charcoal. Electric starters are used to heat the charcoal briquettes, and therefore eliminate the need for lighter fluid. The only emissions are those from the charcoal,[4] and the primary disadvantages are the need for a nearby electrical outlet and the chance of destroying the starter if it is left in the hot coals too long.

Solid starters, which usually consist of wood shavings held together with paraffin, are one of the most inconvenient alternatives. The charcoal must be arranged around the pieces of starter, and this method takes the longest to start the charcoal.[8]

Chimney starters are relatively new on the market, and resemble pieces of metal stove pipe. A piece of newspaper is placed in the bottom of the tube and charcoal is piled on top. A draft is created from the ignition of the

newspaper in the bottom of the chimney starter, and the flames are drawn up through the charcoal. The need for lighter fluid is eliminated. The emissions from this method are those from the charcoal and the piece of paper. The inconvenience of this method lies in the tricky task of removing the chimney once the coals are hot.

The use of an alcohol-based gel starter with charcoal briquettes may cause some alcohol emissions in addition to those from the charcoal combustion. The gel may result in lower evaporative emissions than liquid lighter fluid because it does not require a soaking period prior to lighting. No quantitative emissions data were located, however.

Self-lighting charcoal eliminates the need to apply lighter fluid, and eliminates the emissions associated with evaporation of the fluid during the soaking period. Emissions are expected from combustion of the charcoal and the naphtha component of the charcoal, however.[4] Self-lighting charcoal and self-lighting charcoal in a bag are both easier to use than regular charcoal and lighter fluid, but one disadvantage is that if more charcoal is needed, regular charcoal must be added.

As presented in Table 4, the use of charcoal briquettes and lighter fluid are expected to have the highest emissions of all the alternatives discussed in this report.

SECTION 5

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APPENDIX A

EVAPORATIVE DATA PROVIDED BY THE CLOROX COMPANY

(U. S. TESTING)[3]

APPENDIX A. EVAPORATIVE DATA PROVIDED BY THE CLOROX COMPANY (U. S. TESTING)[3]

Time (Min)	Weight Loss (% of Applied)
0.0	0.0
1.0	0.65
2.0	1.1
3.0	1.4
4.0	1.9
5.0	2.4
6.0	2.9
7.0	3.4
8.0	3.8
9.0	4.4
10.0	4.9

APPENDIX B

EMISSION TESTS OF TWO KEY AREA SOURCES: LAWNMOWER AND CHARCOAL LIGHTER FLUID EMISSIONS

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April 20, 1989

EMISSION TESTS OF KEY AREA SOURCES

INTRODUCTION

As part of AEERL's overall research program in area sources of VOC emissions related to the ozone non-attainment problem, emission tests were performed on two key area sources. The two sources chosen for the test were gasoline lawnmowers and charcoal grills. These two sources were chosen because limited data currently exist and emissions from these sources are expected to show some correlation with population. Since ozone non-attainment tends to occur in populated areas, it was desirable to learn more about the quantities and types of emissions resulting from their use.

This report describes the test facilities, tests, and results. It should be emphasized that the data presented was obtained (for experimental purposes only) without benefit of quality assurance and has not been duplicated. Therefore, all data should be viewed as strictly preliminary.

TEST FACILITIES AND ANALYSES

The tests were conducted in a small outbuilding (3.0 x 3.0 x 2.7 m, 10 x 10 x 9 ft). The temperature-controlled combustion air delivery system was configured to permit the introduction of approximately 35.5 m^3/min (1,253 ft^3/min) of air (1.4 air exchanges/min) to the chamber. Deflectors were positioned so that incoming air did not blow directly onto the emission source. Since the experiment was designed to simulate outdoor use of the two sources in a controlled environment, this air delivery system maintained ambient temperatures and ensured that chamber oxygen concentration always exceeded 20% by volume.

Continuous gas-phase samples were extracted from the combustion chamber through a heated 15.2 m (50 ft) long, 9.5 mm (3/8 in.) outside diameter Teflon sample line equipped with a particle filtration system. Part of this sample was further conditioned for the removal of moisture and analyzed by the individual continuous emission monitors (CEMs) (CO, CO_2, O_2). A portion of the heated gas sample was collected and analyzed for SO_2 and total hydrocarbons (THC). No other sampling and analysis was performed due to limitation of funds.

EQUIPMENT AND TEST PROCEDURE

Lawnmower

The gasoline-powered lawnmower used for the emissions test was a Briggs and Stratton 3.5 horsepower, push model with 22 inch blades. It is manufactured by Murrey Ohio Manufacturing Company and the model number is 7-2226x91. The following steps were used for the test:

1. Start mower
2. Maintain low idle
3. Increase idle to 3/4 load
4. Shut off mower
5. Remove mower from hut

Charcoal Grill

The charcoal grill used for the test was the Little Weber grill. However, the lid which comes with the grill was not used during any part of the test. Approximately 900 g (2 lbs) of charcoal were used with approximately 100 ml of lighter fluid. The following steps were used for the test.

1. Spray on lighter fluid
2. Light fire
3. Remove grill from hut

RESULTS AND DISCUSSION

The CEM data for the lawnmower and charcoal grill test are presented in Tables 1 and 2, respectively. No significant change was seen in the O_2 measurement, indicating that ambient conditions were simulated as designed. Likewise, no changes were noted for CO_2 to SO_2 during the tests. CO and THC concentrations were found to vary during the tests with changes in conditions.

Figures 1 and 2 present the CO and THC concentrations graphically with test conditions indicated for the lawnmower and charcoal grill, respectively. Figure 1 shows that the CO level for the lawnmower increased smoothly after the mower was started, with a rapid increase following the increase in idle to 3/4 load. After this rapid increase, a plateau was reached at about 220 ppm before the mower was shut off. After the mower was shut off, the CO level rapidly fell to background levels. A maximum of 11 ppm THC was reached at 35 minutes, at approximately the same time the CO level reached its plateau.

Figure 2 shows an increase in THC to about 6 ppm, after the lighter fluid was sprayed on the charcoal. Both THC and CO peaked about 15 minutes after the fire was lit at maximums of 34 and 148 ppm, respectively. THC showed a fairly rapid decrease after the maximum followed by a slow decline until the grill was removed from the test facility. CO declined rapidly after the maximum was reached and slowly rose to a second peak shortly before the grill was removed. The THC and CO peaks at 15 minutes can possibly be attributed to the combustion of the charcoal lighter fluid remaining after volatilization with the second CO peak due to the smoldering of the charcoal.

CONCLUSIONS

Again, the data presented should be considered as preliminary. The tests were not repeated and no quality assurance was applied. However, they may be used for order of magnitude estimates for each source. Additional data are needed on the use of each of these sources to project emission estimates.

TABLE 1

LAWNMOWER EMISSIONS TEST

TIME (Minutes)	O2 (%)	CO2 (%)	CO (ppm)	SO2 (%)	THC (ppm)	REMARKS
0	21.1	0	1	0	2	
5	21.0	0	1	0	3	Start mower
10	21.0	0	45	0	7	
15	21.0	0	67	0	5	
20	21.0	0	79	0	6	
25	21.0	0	85	0	6	Increase idle
30	21.0	0	149	0	10	
35	21.0	0	218	0	11	
40	21.0	0	216	0	10	
45	21.0	0	221	0	10	Shut off mower
50	21.0	0	85	0	5	
55	21.0	0	2	0	4	
60	21.1	0	2	0	4	
65	21.0	0	2	0	3	Remove mower
70	21.1	0	2	0	3	
75	21.1	0	1	0	3	
80	21.0	0	1	0	3	

TABLE 2

CHARCOAL GRILL EMISSIONS TEST

TIME (Minutes)	O2 (%)	CO2 (%)	CO (ppm)	SO2 (%)	THC (ppm)	REMARKS
0	21.1	0	2	0	2	
5	21.1	0	1	0	2	
10	21.1	0	1	0	2	Added lighter fluid
15	21.0	0	1	0	6	
20	21.1	0	1	0	7	
25	21.0	0	2	0	7	Lit fire
30	20.9	0	5	0	4	
35	20.9	0.1	41	0	27	
40	20.9	0.1	148	0	34	
45	20.9	0.1	93	0	11	
50	20.9	0.1	88	0	6	
55	20.9	0.1	92	0	4	
60	20.9	0.1	102	0	3	
65	20.9	0.1	114	0	3	
70	20.9	0.1	112	0	2	Removed grill
75	21.0	0.1	45	0	2	
80	21.0	0.1	2	0	2	
85	21.0	0	1	0	2	

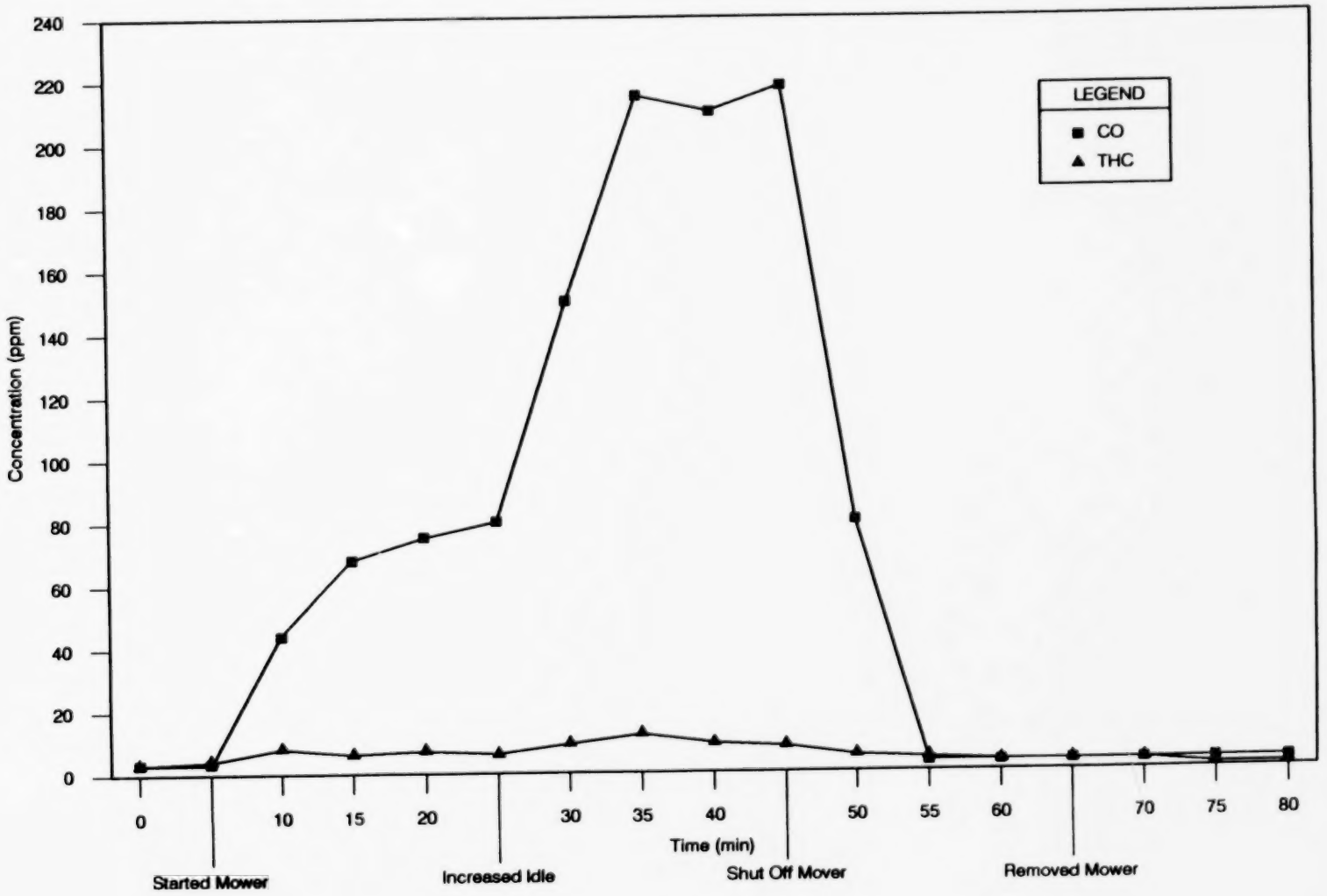

Figure 1. AEERL Lawn Mower Emissions Test

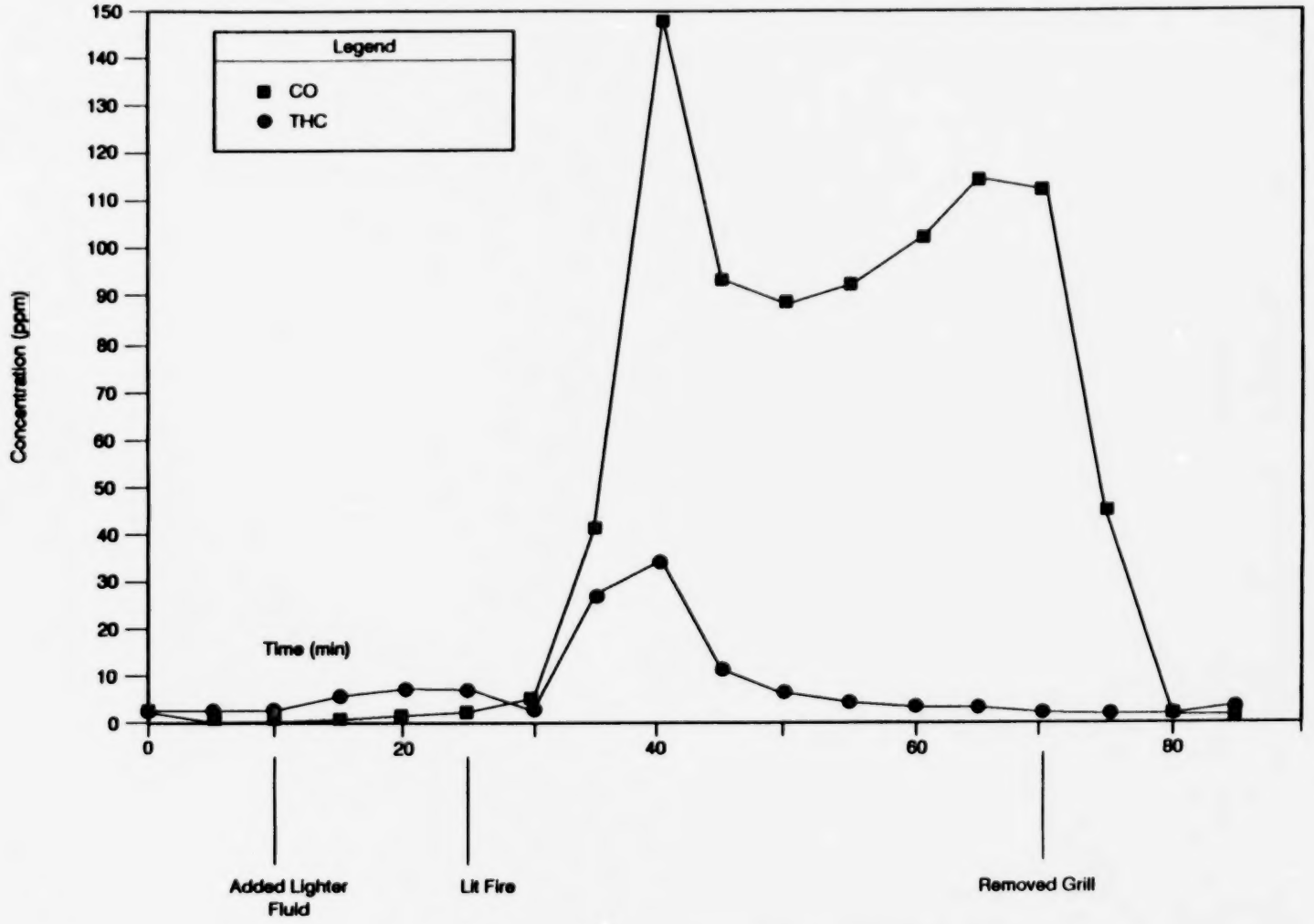

Figure 2. AEERL Charcoal Grill Emissions

APPENDIX C

CONVERSION OF CO_2, CO, AND THC TO EMISSION RATES

CONVERSION DESCRIPTION

The following discussion presents the method for converting the measured concentrations and air flows to emission rates of lighter fluid from barbecues. Results from the April 20, 1989 test report were used to predict emission rates. The concentrations reported for total hydrocarbons (THC) are reported as parts per million (ppm) of propane, or moles of propane per million moles air. The baseline concentration of 2 ppm was assumed to be a background concentration. The following example calculation demonstrates the conversion from THC concentration reported to THC emissions (as propane - C_3H_8).

Example Calculation

Time = 5 minutes

THC Concentration = 6×10^{-6} (moles propane/mole air) = 6 ppm

THC Concentration (less background concentration) = 4×10^{-6} moles propane/mole air.

Air Flow Rate = 1253 ft^3 air/min

Temperature = 77°F = 537°R

Gas Constant = 0.7302 ft^3 air • ATM/lb-mol air • °R

Pressure = 1 ATM.

Emissions (lb THC (as propane) =

$$\frac{(1253\ ft^3\ air/min) \times (4 \times 10^{-6}\ lb\ moles\ propane/lb\ mole\ air)}{(0.7302\ ft^3\ air \cdot ATM/lb\text{-}mol\ air \cdot °R) \times (537°R/1\ ATM)}$$

$$\times (44\ lb\ mole\ propane/lb\ propane)$$

$$= 5.62 \times 10^{-4}\ lb\ THC\ (as\ propane)/min$$

Assuming that evaporative emissions occurred during the time that the 15 minute, 20 minute, and 25 minute readings were collected, the emissions from evaporation over this 15 minute period were 0.0633 lb THC (as propane). This represents 6% of the total quantity of lighter fluid applied. The following example calculation demonstrates the method used to develop these estimates.

Example Calculation

$(5.62 \times 10^{-4}$ lb/min) x 5 min + $(7.03 \times 10^{-4}$ lb/min) x 5 min +
$(7.03 \times 10^{-4}$ lb/min) x 5 min = 0.0098 lb THC (as propane)

0.0098 lb THC/0.1631 lb lighter fluid

= 6.00% emitted from evaporation

Emissions from combustion and evaporation were calculated in a similar manner. Emissions up through the first CO peak (at 40 min) and prior to the second CO peak (at 50 min) were calculated in the same manner to be 0.0513 lb and 0.0605 lb, respectively.

APPENDIX B. CONVERSION OF CO2, CO, AND THC TO EMISSION RATES

Air flow rate 1253 cub.ft/min
Temperature = 77 deg F

Time (min)	CO2 (ppm)	CO (ppm)	THC (ppm)	CO2 emissions as CO2 (lb/min)	CO2 emissions as C (lb/min)	CO emissions as CO (lb/min)	CO emissions as C (lb/min)	THC emissions as C3H8 (lb/min)	THC emissions as C (lb/min)
0	0	2	2	0	0	0.000	0.0000	0	0
5	0	1	2	0	0	0	0	0	0
10	0	1	2	0	0	0	0	0	0
15	0	1	6	0	0	0	0	5.62E-04	4.60E-04
20	0	1	7	0	0	0	0	7.03E-04	5.75E-04
25	0	2	7	0	0	0.000	0.0000	7.03E-04	5.75E-04
30	0	5	4	0	0	0.000	0.0002	2.81E-04	2.30E-04
35	1000	41	27	0.141	0.0383	0.004	0.0015	3.52E-03	2.88E-03
40	1000	148	34	0.141	0.0383	0.013	0.0056	4.50E-03	3.68E-03
45	1000	93	11	0.141	0.0383	0.008	0.0035	1.27E-03	1.04E-03
50	1000	88	6	0.141	0.0383	0.008	0.0033	5.62E-04	4.60E-04
55	1000	92	4	0.141	0.0383	0.008	0.0035	2.81E-04	2.30E-04
60	1000	102	3	0.141	0.0383	0.009	0.0039	1.41E-04	1.15E-04
65	1000	114	3	0.141	0.0383	0.010	0.0043	1.41E-04	1.15E-04
70	1000	112	2	0.141	0.0383	0.010	0.0043	0	0
75	1000	45	2	0.141	0.0383	0.004	0.0017	0	0
80	1000	2	2	0.141	0.0383	0.000	0.0000	0	0
85	0	1	2	0	0	0	0	0	0
Totals				7.03	1.92	0.373	0.160	0.0633	0.0518
							Evaporation	0.0098	
							Prior to 2nd	0.0605	
							Prior to 1st	0.0513	